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(54) Electrically heated laminated window.

(57) A transparent, laminated window, particularly for use as a vehicle windshield, has improved deicing capability and high luminous transmission and near IR rejection, comprises an optical element having a low sheet resistivity of less than about 3 ohms per square, such element containing at least two transparent metal layers electrically conductively associated with bus bar(s) and separated by one or more dielectric layers.

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Description

ELECTRICALLY HEATABLE LAMINATED WINDOW

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BACKGROUND OF THE INVENTION

This invention relates to transparent laminated windows and more particularly to such windows having improved defrosting capability.

10 With the advent of aerodynamic motor vehicle bodies having severely sloping front and rear windows to reduce drag and conserve fuel, automobile windows are increasing in surface area with each model year. This has disadvantages in that the inside of the motor vehicle becomes quite hot in summer while in winter it takes longer to defrost or deice and defog quickly and uniformly using conventional motor vehicle generator voltages. As disclosed in U.S. 4,017,661, transparent laminated windows which can be electrically defrosted
15 are known. However, the amount of heat producible with motor vehicle generated voltages in such prior art windows is limited, which disadvantageously extends the time for clearing extended surface windshields. It would be desirable to reduce the time for clearing laminated windows of ice and condensation.

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SUMMARY OF THE INVENTION

Now improvements have been developed which alleviate shortcomings of the prior art and facilitate removal of ice and condensation from laminated windows.

25 Accordingly, a principal object of this invention is to provide an improved electrically conductive motor vehicle windshield.

Another object is to provide a transparent, laminated window having improved resistive heating capability for removing ice and condensation from its surfaces.

30 A specific object is to provide an improved, electrically conductive windshield containing an optical element capable of both high transmittance (more than 70%) and low reflection (less than 16%) of visible radiation required for motor vehicle applications and significant rejection, primarily by reflection, of near infrared (IR) solar radiation, to minimize heat buildup in the vehicle compartment.

Other objects of this invention will in part be obvious and will in part appear from the following description and claims.

35 These and other objects are accomplished by electrically connecting first and second metal layers of an optically efficient multi-layer metal/metal oxide interference filter element to a source of electric energy to decrease sheet resistivity and approximately double the power deliverable to the element (vis-a-vis one containing a single metal layer), thereby increasing electrically generated heat and reducing defrost and/or demist time. The metal layers are spaced from each other in the optical element by an amount which causes
40 visible (i.e. luminous) light reflectance from each of the layers to destructively interfere so as to suppress undesirable luminous reflectance and enhance desirable luminous transmission of the window containing the optical element.

More specifically, a transparent, laminated window is provided having improved defrosting capability comprising: A) an optical element having a sheet resistivity of less than about 3 ohms per square containing: i)
45 at least two electrically conductive metal layers; ii) one or more dielectric spacing layers separating such conductive layers; and iii) a transparent substrate; and B) a bus bar electrically conductively associated with each conductive layer.

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DETAILED DESCRIPTION OF THE INVENTION

The optical element component of the laminated window of the invention is an interference filter of the Fabry-Perout type designed, principally through the appropriate selection of materials and their thicknesses to
55 maximize i) transmission of visual or luminous and ii) reflection of heat-generating infrared portions (700-2125 nm) of the solar spectrum. Such element consists of multiple, sequentially deposited planar layers of angstroms-thick metal and dielectric coatings arranged in a predetermined sequence in face-adhering, contiguous contact with each other, of the type generally disclosed in U.S. Nos. 3,682,528 and 4,179,181.

The inventive optical element must contain at least two electrically conductive, near IR reflecting metal
60 layers which, when operatively positioned in the element, result in a transmission of at least 70% visible light of normal incidence measured as specified in ANSI Z26.1, this being the minimum required in the U.S. automotive industry. Preferably visible light reflectance, normal from the surface of the element is less than 16%. The metal layers of the optical element must be separated (i.e. vertically in the thickness direction) from each other

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by one or more dielectric layers conventionally used in interference filters so that reflection of visible light from the two adjacent separated metal layers interferes destructively thereby enhancing visible transmission. Usable metals comprise silver, aluminum, chrome, nickel, brass, gold, stainless steel, copper, and alloys or claddings of any of the foregoing. The preferred metal for each of the layers is silver.

Each metal layer should be continuous and highly conductive to attain reduced thawing periods without deterioration in the visible light transmission and near infrared solar rejection properties of the element. Reduced thawing time is achieved by using the second metal layer (though more than two may be present and each may be used) along with the first metal layer to conduct electricity for heating the window. The rapidity at which an applied voltage can defrost a window is determined by the sheet resistivity of the optical element. This is the resistance measured between buss bars extending across opposite sides of a square element. Since vehicle windshields approximate a 2 by 1 rectangle, the actual buss to buss resistance will be equal to approximately one half of the sheet resistivity. The sheet resistivity of the optical element of the invention should not exceed 3 and preferably be less than 2.5 ohms per square which, it is estimated, should provide a defrost time of less than two minutes at 0°F. Even slight metal layer discontinuity drastically decreases electrical conductivity and luminous transmittance. To achieve desired continuity, the metal film should have a thickness of at least about 60 angstroms. Thinner films become unstable and tend to agglomerate and decrease in electrical conductance and luminous transmittance with time. The thickness, however, should not significantly exceed about 300 angstroms to avoid unacceptably low luminous transmittance.

The dielectric layer(s) of the optical element must be essentially transparent over the solar range (i.e. from 325 to 2125 nm) and at least one must exist between each pair of electrically conductive metal layers. Preferably, a dielectric layer is positioned on each side of a metal layer. Exemplary usable dielectric materials include SiO, SiO₂, Ta₂O₅, WO₃, In₂O₃...SnO₂, Al₂O₃, In₂O₃, MgF₂, ZnS, and ZnO₂; TiO₂ is preferred for each dielectric layer.

The substrate of the optical element comprises one or plural layers, one of which directly supports the optical element in that a layer of the latter rests in face to face contact on the substrate surface. The substrate can be selected from a variety of materials with choice generally governed by the compatibility between the optical element and the substrate. Usable substrates should not be prone to stretch to avoid cracking the metal/dielectric layers and should be free of excess amounts of volatiles such as plasticizers, water vapor or absorbed gases. The dielectric layer of the optical element in direct contact with the substrate should adhere well to the substrate surface. Generally the optical element of the invention adheres well to glass, ceramics and certain flexible plastics such as polyesters, cast acrylics, polycarbonates, chlorinated plastics and epoxies. Polyurethanes and polyvinyl butyral as a substrate component in direct supportive contact with the optical element are too soft and extensible. Preferred substrates are sheets of transparent materials such as glass or non-extensible flexible plastic materials such as linear polyesters, e.g. polyethylene terephthalate which is commercially available as Mylar®. In a preferred construction the optical element is sequentially deposited on a flexible sheet substrate of polyethylene terephthalate (PET), and then the substrate carrying the optical element is encapsulated within two layers of conventional plasticized polyvinyl butyral (PVB), one layer of which abuts the PET substrate and the other abuts the top layer of the optical element. The multi-layered "sandwich" containing PVB as the outer layers is then conventionally laminated between two rigid members such as glass panes, or alternatively may be used as a bilayer structure by laminating it to one such rigid member intended to be the exterior side of a window. Besides glass, other rigid transparent sheets such as polycarbonate and acrylic are usable. Lamination must not significantly affect the electrical conductivity of the optical element, nor reduce the visible light transmission or near IR reflectance by more than about 8%. For motor vehicle window applications the flexible plastic substrate sheet of the sandwich referred to above should have a thickness of about 1 to about 8 mils, the individual sheets of plasticized PVB should be about 5 to about 60 mils thick and the rigid transparent member should be from 60 to 500 mils thick.

As generally known in the art, varying the thickness and composition of a dielectric layer spaced between two reflecting metal layers, will vary the optical transmittance/reflection properties of the optical element considerably. More specifically, varying the thickness of the spacing dielectric layer varies the wave length associated with the reflection suppression (or transmission enhancement) band. In addition to choice of metal, its thickness also determines its reflectivity, the thinner the layer, the less its reflectivity. For maximum reflection attenuation, the reflection of the two metal layers should be equal. As reflectivity of the two metal layers is reduced, the width of the reflection suppression band widens. Generally, the thickness of spacing dielectric layer(s) should be between about 200 to about 1200 and preferably between 450 to 1000 angstroms to obtain the desired optical properties and film continuity necessary for a commercially acceptable product. Metal oxide dielectric layers less than about 200 or more than about 1200 angstroms result in very low luminous transmittance.

Exterior dielectric layers in contact with the metal layer surfaces opposite to the metal surfaces contacting spacing dielectric layer(s) are preferably used to enhance anti-reflection performance. Exterior dielectric layers generally should have a higher refractive index than glass or polyvinyl butyral, i.e. greater than 1.5 and preferably greater than 1.8. The thickness of such exterior or outside dielectric layer(s) is generally less than the spacing dielectric layer(s) and should be about 100 to about 600 and preferably 160 to 500 angstroms.

Individual layers of the optical element are deposited by vacuum coating techniques well known in the art such as vacuum evaporation or sputtering. Usable methods include evaporation (resistance heated, laser heated, or electron-beam vaporization) and sputtering (diode or magnetron) under normal or reactive

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conditions.

The laminated window of the invention can be used in any application requiring a transparent resistance-heated window. The preferable environment is where fast deice or thaw intervals and good near IR rejection and luminous transmission of solar radiation is desired. Typical applications include automotive windshields and architectural applications such as commercial and residential buildings.

The invention is further described with reference to the following examples which are for illustration only and are not intended to imply any limitation or restriction on the invention.

All samples described in the Examples were prepared on 5 cm square 3 mm thick glass plate substrates. Prior to coating, i.e. deposition of the optical element thereon, each glass plate was mechanically washed in detergent solution then rinsed and immersed in a 50/50 volume % solution of concentrated sulfuric acid and 30% hydrogen peroxide. After removal the plates were sequentially rinsed in distilled water and isopropanol, blown dry with nitrogen and placed in a vacuum chamber. After pumping the chamber to a base pressure less than 1×10^{-5} mbar, argon was introduced at a flow of 30 sccm to give a pressure of 3×10^{-3} m bar. The glass substrates were rf etched (13.56 MHz, the resulting dc voltage was 200 volts) for 10 minutes.

All vapor deposited coatings or layers were sequentially applied serially, one on top of the other, by magnetron sputtering using a Leybold Heraeus sputter coater, the first layer being deposited on the glass plate surface. Titanium oxide and tungsten oxide were reactively prepared using round metallic targets which had a diameter of about 7.5 cm and an area of about 44 square centimeters. Layer thicknesses were monitored using an Inficon XTC crystal monitor.

Optical properties before and after lamination were determined with a Perkin Elmer 330 UV/VIS/NIR spectrophotometer. When reflectance measurements were made the optical element, i.e. the glass plate containing the coating layers, was placed nearest the integrating sphere. Laminates were prepared with the outer vapor deposited layer in face to face contact with a PVB interlayer in the form of 30 mil thick Saflex® sheet. The sequential layers of a laminate were: optical element (i.e. coated glass substrate) /PVB/glass. In preparing a laminate, the coated glass /PVB/glass stack was preheated at 150°C for 15 min. and a pressure of 40 psi applied for 5 min. while maintaining such temperature. With the pressure maintained the laminate was then allowed to cool to room temperature.

Sheet resistivities were measured with an Alessi Model A4P series four point probe using a 3 volt power supply.

Abbreviations used in data in the Examples are defined as follows:

Tv, Rv and Av = respectively, visible transmission, reflectance and absorption

Ts, Rs and As = respectively, solar transmission, reflectance and absorption

SR = solar energy rejection calculated under standard summer conditions specified in ASHRAE Handbook, 1985, chapter 27 - i.e. $\% SR = 100\% - \%Ts - 0.27 \times \%As$

RES = sheet resistivity in ohms per square

WO3 = tungsten oxide

A = angstroms

Examples labeled "LAM" represent laminated samples while those without such designation were unlaminated - i.e. were only the glass substrate -multi-layer coating combination per se.

COMPARATIVE EXAMPLES C1-C3

These comparative Examples of an optical element containing a single metal layer are not according to the invention.

Optical element samples containing single silver layers of various thicknesses and dielectric layers on either side of the silver layer were prepared. Dielectric layer thicknesses were varied to achieve maximum visible transmission with each silver layer thickness. Deposition conditions and recipes were as follows:

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Ex.	Film Comp.	Flow Rate		Total Press. minbar	DC Power Watts	Film Thickness A	Deposition Rate A/sec.
		Argon sccm	Oxygen sccm				
C1	TiO2	30	12.0	3.5	350	283	1.5
	Ag	30	---	3	44	180	20
	W03	30	1.0	3	18	60	1.0
	TiO2	30	12.0	3.5	350	249	1.5
C2	TiO2	30	12.0	3.5	350	350	1.4
	Ag	30	---	3	44	240	20
	W03	30	1.0	3	18	60	1.0
	TiO2	30	12.0	3.5	350	310	1.4
C3	TiO2	30	12.0	3.5	350	375	1.4
	Ag	30	---	3	44	280	20
	W03	30	1.0	3	18	60	1.0
	TiO2	30	12.0	3.5	350	335	1.5

Performance data obtained on each sample is given in the following Table 1.

TABLE 1

Example	Ag Thick- ness (A)	%Tv	%Rv	%Av	%Ts	%Rs	%As	%SR	RES
C1	180	84.2	6.3	9.4	53.8	37.4	8.8	44	3.18
LAMC1		76.6	11.4	11.9	48.2	29.2	22.5	46	
C2	240	85.2	7.2	7.6	52.0	40.9	7.0	46	2.24
LAMC2		72.1	17.2	10.7	42.7	36.5	20.8	52	
C3	280	78.6	15.9	5.5	44.2	50.1	5.8	54	1.76
LAMC3		62.8	25.7	11.6	35.2	43.6	21.2	59	

From the above performance data; though Tv exceeds 70% at 180A silver layer thickness in LAMC1, RES exceeds 3.0; at 280A silver thickness in LAMC3 RES is below 3 but %Tv is below 70; for LAMC2, though RES is below 3.0 and Tv exceeds 70% Rv is greater than 16%. For windshield applications 16% Rv is considered a maximum since in excess of this a safety hazard can be created in driving applications particularly during night driving where light within the vehicle can be dangerously reflected from the windshield into the eyes of the driver.

EXAMPLES 1 AND 2

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These Examples containing dual metal layers are according to the invention.
Optical element samples containing dual metal layers were prepared.

5	Ex.	Film Comp.	Flow Rate		Total Press.	DC Power Watts	Film Thickness A	Deposition	
			Argon	Oxygen				Rate	A/sec.
			sccm	sccm	mmbar				
10	1	TiO2	30	12.0	3.5	350	283	1.4	
		Ag	30	---	3	44	140	20	
		WO3	30	1.0	3	18	60	1.0	
15		TiO2	30	12.0	3.5	350	576	1.5	
		Ag	30	---	3	44	140	20	
		WO3	30	1.0	3	18	60	1.0	
20	2	TiO2	30	12.0	3.5	350	249	1.4	
		TiO2	30	12.0	3.5	350	283	1.4	
		Ag	30	---	3	44	180	20	
25		WO3	30	1.0	3	18	60	1.0	
		TiO2	30	12.0	3.5	350	576	1.5	
		Ag	30	---	3	44	180	20	
30		WO3	30	1.0	3	18	60	1.0	
		TiO2	30	12.0	3.5	350	249	1.4	

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The electrical and optical performance of each is given in the following Table 2.

TABLE 2

40	Example	Ag Thick- ness (A)	%Tv	%Rv	%Av	%Ts	%Rs	%As	%SR	RES
45	1	140	77.6	3.5	18.9	44.2	41.2	14.6	52	2.10
	LAM1		71.5	7.4	21.1	38.9	34.7	26.6	54	
50	2	180	76.4	4.9	18.5	39.8	43.3	16.1	56	1.8
	LAM2		72.9	7.4	19.8	37.2	36.0	26.9	56	

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As evident in comparing the data for the laminated samples employing 180A silver thickness in Example 2 in Table 2 and Example C1 in Table 1, with the inventive optical element of Example 2 RES is reduced by a factor of about 2 (i.e. from 3.2 to 1.8), visible normal reflectance is reduced from 11.4 to 7.4 and solar rejection is increased by 10% from 46% to over 50% - i.e. 56%.

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While certain specific embodiments of the invention have been described with particularity herein, it will be recognized that various modifications thereof will occur to those skilled in the art. The scope of the invention, therefore, is to be limited solely by the scope of the following claims.

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Claims

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1. A transparent, laminated window having improved defrosting capability comprising, in combination,:
 - A) an optical element having a sheet resistivity of less than about 3 ohms per square containing:
 - i) at least two electrically conductive metal layers;
 - ii) one or more dielectric spacing layers separating said conductive layers; and
 - iii) a transparent substrate; and
 - B) a bus bar electrically conductively associated with each conductive layer.
 2. The window of claim 1 wherein the conductive layers are silver having a thickness of from about 60 to about 300 angstroms.
 3. The window of claim 1 wherein a dielectric layer is titanium dioxide having a thickness of from 200 to 1200 angstroms.
 4. The window of any of claims 1, 2 or 3 wherein the optical element has a sheet resistivity of less than 2.5 ohms per square.
 5. The window of claim 4 including flexible plastic layers within which said optical element is encapsulated.
 6. The window of claim 4 wherein the transparent substrate for the optical element is glass.
 7. The window of claim 4 having a visible transmission of at least 70%.
 8. The window of claim 4 having a visible reflection of no more than 16%.
 9. The window of claim 4 having a solar rejection of at least 50%.
 10. The window of claim 5 wherein the flexible plastic comprises polyvinyl butyral.
 11. A transparent, laminated window capable of transmitting at least 70% of visible light, rejecting at least 50% of solar radiation and having improved defrosting capability, said window comprising:
 - A) an optical element having a sheet resistivity less than 3 ohms per square containing:
 - i) at least two electrically conductive metal layers;
 - ii) one or more dielectric spacing layers separating said conductive layers; and
 - iii) a transparent substrate; and
 - B) a bus bar electrically conductively associated with each conductive layer.
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